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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Interpretation of FRESCO cloud retrievals in case of absorbing aerosol events" *by* P. Wang et al.

P. Wang et al.

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We would like to thank referee #3 for the comments and helpful suggestions. The manuscript is revised according to the referee's suggestions. The simulations are performed using Mie scattering phase functions for biomass aerosols and dust aerosols in clear-sky and cloudy cases. We have used more aerosol optical thickness values in the simulations.

Interactive comment on 'Interpretation of FRESCO cloud retrievals in case of absorbing aerosol events' by P. Wang et al. Anonymous Referee #3 Received and published: 6 February 2012

The paper from Wang et. al. discusses the results of the FRESCO cloud algorithm together with the aerosol absorbing index. Both data products are established for spectrometers like GOME, GOME-2 and SCIAMACHY. The FRESCO algorithm is part of the official Level-2 data product and has a high importance for the scientific community. An impact of aerosols to the GOME cloud data is plausible and expected with respect to the retrieval methods used. Nevertheless, a detailed study is not yet published and an important task for a scientific paper.

The paper contains some interesting and promising results. In general, I think there are two objectives of these studies which can be a focus of the scientific paper: 1.) The impact of aerosol events to the FRESCO cloud retrieval. 2.) Retrieval of aerosol parameters in addition to cloud parameters

It is not clear to me, which of these options would be a better focus of the paper. In both cases some studies should be added (see below) and the objective of the paper should be explained more in detail. The conclusions in sect. 5 and the abstract are very optimistic, in particular with respect to the benefit for aviation safety and operations. I think this should be removed or discussed in detail with respect to the points below.

A meaningful, quantitative interpretation of the FRESCO results as aerosol layer height requires running the algorithm in a different mode using scene albedo and scene pressure. What would be the threshold in the AAI, where FRESCO could switch from the usual retrieval mode to a mode using scene albedo and scene pressure? Are vulcanic ash plums usually / always above this threshold?

A: The referee is right in the observation that this type of studies could have two objectives, namely to quantify the effect of absorbing aerosols on cloud retrievals, and to retrieve absorbing aerosol parameters in addition to cloud parameters. The objective of our paper is a combination of the two. The FRESCO retrievals are performed for all scenes globally. For scenes with absorbing aerosols the information could be aerosol information, or if there are clouds, a mixture of aerosol and cloud information. The new simulations give quantitative relationships between AOT of realistically absorbing aerosols and FRESCO retrievals. The objective of the paper is now better discussed in the introduction.

It is difficult to set a strict threshold in the AAI for aerosol versus cloud detection. For clear-sky scenes, FRESCO scene pressure may be interpreted as aerosol pressure for optically thin aerosols which have relatively small AAI values, for example AAI=1-2. For cloudy scenes, FRESCO only retrieves aerosol height for extremely optically thick and absorbing aerosols which have an AAI value larger than 8. Currently we provide in the FRESCO product all four quantities: cloud pressure, effective cloud fraction, scene pressure and scene albedo. These are given for all scenes. The user can combine this FRESCO information with aerosol information, whether it is from the AAI or from other sources (e.g. other satellite instruments). The FRESCO algorithm is designed to retrieve cloud height and effective cloud fraction. The aerosol height is more like a special application of FRESCO retrievals. Usually the volcanic ash plumes are optically thicker if the plume is close to the volcano. If they are transported and aged, the AAI values will be smaller.

What is the limit in AOD to retrieve reliable values for aerosol pressure using FRESCO? What kind of absorbing aerosols would typically fulfil this limit?

A: For clear-sky cases, if AOD >0.1 at 760 nm, the FRESCO algorithm could retrieve biomass burning aerosol pressure using the assumption of cloud albedo of

0.8. For aerosols above fully cloudy scenes, AOD = 2 at 760 nm is the lower limit for the retrieval of aerosol height. The AOD limit varies with the absorption of the aerosols. In order to retrieve heights of less strongly absorbing aerosols, the AOD values should be larger. Because the wavelength dependence of AOD varies for different types of aerosols, the AOD at UV and visible wavelength can be a factor of 2 or larger than the AOD at 760 nm. We have discussed the limit in AOD in Section 3.

I think the results could be useful, even if there would be only a limited amount of cases to apply the technique, because the combination of the o2-A-band and the AAI is an interesting approach: The AAI is a function of several aerosol properties, including AOD, SSA and aerosol layer height. Could the AAI be transformed into a more useful value, if the AOD and the layer height is known? If this is not the case, which additional information would be required? Unfortunately this is not really discussed within the paper.

A: We agree with referee #3 that combination of AAI and cloud height from O2 A band may give more information. As explained by referee #1:

'Knowledge of aerosol layer height is not enough to derive aerosol optical depth (AOD) from the AAI. Information on single scattering albedo is also required. Both AOD and SSA can be simultaneously derived (if aerosol height is known) using observations of AAI and reflectance at a near UV channel.'

This is certainly a good topic for future research. We added this to the Conclusions.

If the authors would like to discuss the first objective, they should quantify the error in effective cloud fraction and cloud pressure in the case of absorbing aerosol events and should discuss the possibility to improve FRESCO cloud retrievals using the AAI.

Maybe it is a good idea to set a flag in the FRESCO product, if the cloud fraction / pressure is influenced by an absorbing aerosol?

A: It's a good idea to set a flag in the FRESCO product if the cloud fraction/ pressure is influenced by an absorbing aerosols. But actually, for SCIAMACHY and GOME-2, we already have collocated AAI and FRESCO products, so that users can get the AAI values at the same locations as the FRESCO values. For small effective cloud fractions < 0.2 and large AAI, the cloud height may be impacted by aerosols. For the large effective cloud fraction, the cloud height are less influenced by aerosols if AAI is < 5–6.

I wonder, why FRESCO should give the aerosol height instead of the cloud height, if the aerosol is above the cloud. The authors have shown in their previous papers, that the cloud height retrieved by FRESCO usually represents the center of the cloud. Therefore I would not expect to get the aerosol height, if the aerosol layer is above a cloud. In Fig. 2b.), the scene height is between the aerosol and the cloud except for high SZA in the optical thick aerosol case.

A: We have done simulations for single layer clouds and two-layer clouds in our previous paper (Wang et al., ACP, 2008). There we showed that if there is an optically thin cloud layer above an optically thick cloud layer, FRESCO retrieves a cloud height between the two cloud layers. However, in the case of a layer of absorbing aerosols over a cloud layer an additional process is introduced, namely absorption. For an absorbing aerosol layer having a high AOT (about 4) at 760 nm, most of the light reflected from the clouds is being absorbed in the aerosol layer. In the measured refectance at TOA, there is almost no contribution from the clouds, therefore FRESCO can retrieve aerosol height. This is not the case for non-absorbing cloud layers: a cloud layer having COT of 4 on top of a bright cloud layer causes multiple scattering and reflections between the two layers. The sum of all contributions is measured at

TOA, so FRESCO cannot distinguish these two clouds layers. An AOT value of 4 at 760 nm corresponds to an extremely large AOT in the UV and visible wavelengths, which depends on the aerosol particle size, the imagery part of the complex refractive index.

We have also looked at the sensitivity of the O2 A band to the aerosol and cloudy layer height. Fig. 1 shows the altitude resolved Air Mass Factor (AMF) at 760 nm. The altitude resolved AMF values present the sensitivity of the reflectance at TOA to O2 at certain altitudes. Small AMFs suggest low sensitivity to O2 and large AMFs indicate high sensitivity to O2. As shown in Fig. A3, if an absorbing aerosol layer of AOT= 3 resides on top of a cloud layer (COT=20), the sensitivity of the reflectance to O2 below 4 km is very small; therefore, FRESCO retrieves aerosol height. If the aerosol layer is replaced with a cloud layer having COD = 3, the AMFs are still large below 4 km. In this case, the reflectance at TOA has the contribution from the two cloud layers, therefore the retrieved cloud height is a level between these two cloud layers. The cases $COT = 20$, $AOT = 3$ and $COT = 0$, $AOT = 3$ are very similar, which also suggests that the cloud layer or surface has a very small contribution to the reflectance at TOA if there is an optically thick absorbing aerosol layer on top of the cloud layer or surface.

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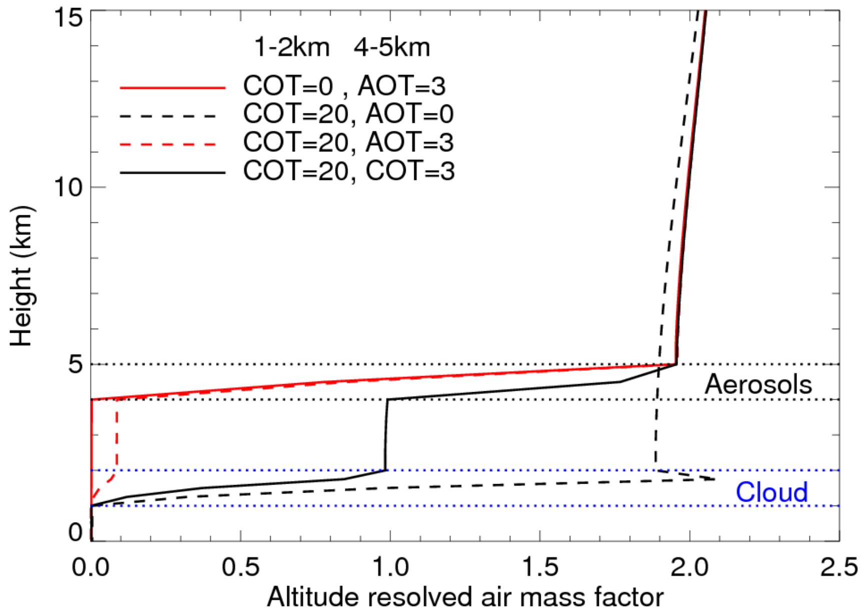

Fig. 1. Altitude resolved AMFs for O2 absorption at 760.061 nm. The O2 optical thickness at 760.061 nm is about 2 (convolved with GOME-2 slitfunction), which is a typical value in GOME-2 O2 A band measurement